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COMMERCIALIZING UNIVERSITY INVENTIONS: ARE CANADIANS LESS PRODUCTIVE THAN AMERICANS?

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Working Paper 2008-01

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Abstract

We review Canadian technology transfer trends over the past 10 years and discover that although inputs to the process of commercializing university science have increased consistently, increases in outputs have been less predictable. Inconsistent growth in patents and licensing revenues are particularly noticeable and warrant further investigation. A pair-wise comparison between one of the largest research institutions in the country (University of Toronto) and a similarly significant American counterpart (Massachusetts Institute of Technology) suggests that, at least in this particular case including normalization for research expenditures, the Canadian institution seems less efficient with respect to the commercialization of research. Moreover, regression analyses based on a sample of 160 universities from Canada and the U.S. provide more suggestive evidence that there may be a Canadian productivity discount in terms of technology transfer. Furthermore, a detailed interview with the chief executive officer of a Canadian firm that has engaged in university technology transfer in a variety of countries reveals that, from at least this firm's perspective, commercialization transactions are more efficient in the U.S. We offer some speculation based on the literature and interview for why that might be.

Key words: university research, commercialization, technology transfer, patents

Résumé

L'étude examine l'évolution des transferts de technologie au cours des 10 dernières années et révèle que, malgré une augmentation constante des ressources investies dans le processus de commercialisation de la science universitaire, l'augmentation des résultats n'a pas été aussi régulière. La croissance irrégulière des revenus tirés de brevets et de licences ressort particulièrement et mérite un examen approfondi. Une comparaison entre une des principales institutions de recherche du pays (l'Université de Toronto) et une institution américaine d'importance semblable (le Massachusetts Institute of Technology) laisse croire que, à tout le moins dans ce cas précis et en normalisant les dépenses de recherche, l'institution canadienne serait moins efficace en ce qui a trait à la commercialisation de ses recherches. De plus, une analyse de régression portant sur un échantillon de 160 universités canadiennes et américaines appuie la theorie selon laquelle il y aurait un retard de productivité du Canada par rapport aux É.-U. en matière de transferts de technologie. Une entrevue approfondie avec le chef de la direction d'une entreprise canadienne qui a pris part à des transferts de technologie dans divers pays montre que, selon cette entreprise à tout le moins, la commercialisation de la recherche est plus efficace aux É.-U. Nous offrons quelques pistes d'explication inspirées de la littérature et de l'entrevue.

Mots clés : recherche universitaire, commercialisation, transferts de technologie, brevets

1. Introduction

The objective of this paper is to offer insights into the transfer of research from Canadian universities to industry. We organize the paper into four sections. The first section offers insight into technology transfer trends over the past 10 years.[1] Focusing on 10 major research universities in Canada, we examine how certain commercialization metrics have changed over time. While investments in research and technology transfer personnel have increased every year during this period, the rate of increase in output measures has been less dramatic and less consistent. We then compare the productivity of two particular institutions: the University of Toronto (UofT) and the Massachusetts Institute of Technology (MIT). While the Canadian institution performs as well as its American counterpart on some dimensions such as the number of invention disclosures, it performs less well on others such as patent applications, patents issued, and licensing revenues (all normalized for institution-level research expenditures).

In the second section, we move from a simple pair wise comparison to a sample of 160 Canadian and American universities.[2] The descriptive statistics suggest that American institutions produce significantly more technology transfer. However, these schools also spend more on research, on average, and so overall technology transfer productivity is less obvious. As a result, we conduct multivariate regression analyses to control for differences in key input factors. The empirical analyses suggest that there is indeed a Canadian commercialization discount. That is, on average and controlling for key input factors such as research funding, Canadian institutions generate fewer patent applications, fewer issued patents, and less licensing revenue than their American counterparts.

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[1] In the context of this paper, the terms "technology transfer" and "technology commercialization" are used interchangeably.
[2] 22 of the 160 universities in the sample are Canadian.

In the third section, we review the recent literature on the economics of university technology transfer. We summarize the factors that have been identified as potential determinants of technology transfer productivity that might vary systematically across countries: 1) national policy (e.g., the Bayh-Dole Act in the US), 2) commercialization culture, 3) access to resources such as venture capital, and 4) proximity to anchor tenants. Extrapolating from prior research, differences in commercialization culture and proximity to anchor tenants seem the most likely candidates for explaining the commercialization discount. We also discuss whether the discount might actually be a positive attribute, referencing the current debate regarding whether commercialization is causing university scientists to substitute patenting activity for publishing. (Publishing is arguably at least equally important for advancing science and technology transfer.) The empirical evidence to date suggests that this is not the case.[3]

Finally, in the last section of the paper, we comment on the demand side of the transfer equation. We describe D-Wave, a Canadian company whose business model is predicated on transferring technology from universities. The company's mission is a very ambitious science-driven project to build the world's first commercial superconductor-based quantum computer processors. Using its university technology transfer strategy with public research institutions around the world, the company has successfully accumulated more patents in this area than its three largest competitors (IBM, Hitachi, and Lucent) combined. We describe the D-Wave business model and analyze three salient features of the local environment at the University of British Columbia (UBC) that seem to have facilitated the formation and growth of this company. Then, since the

[3] This issue is discussed at length in Section 4.5 and includes references to papers that present empirical evidence to support their assertions.

company has transferred technology from multiple American, Canadian, and European institutions, we are able to draw some conclusions at the national level as to why the Canadian commercialization discount might exist, at least from the perspective of a single case example.

2. University Technology Transfer in Canada

University technology transfer is notoriously difficult to measure. New knowledge that can be applied towards the commercialization of scientific or engineering findings is transferred from university labs into the marketplace through a wide variety of channels, including patents and licenses, the recruitment of graduate students, the co-supervising of graduate students (by professors and industry scientists), publications, conference presentations, consulting, informal conversations, and collaborative research. Of these, patents and licenses is the channel most commonly examined by scholars attempting to measure technology transfer, even though it is not the most important in terms of facilitating actual transfer to industry (Cohen et al, 1998; Agrawal and Henderson, 2002).

The problem, of course, is that transfer through the other channels is even more difficult to measure. For example, transfer through channels such as conference presentations, informal conversations, and consulting is not systematically recorded. While publication data is recorded, it is difficult to interpret which publications are responsible for commercially-oriented technology transfer. Patents, on the other hand, are considered a reasonably clear indication of intent to commercialize, and licensing data actually capture measures of transferred value. As such, this paper will examine patent and related data as a proxy for technology transfer but remain mindful that these metrics only represent a fraction of overall transfer activity.

The Association of University Technology Managers' (AUTM) Annual Survey is the primary source of university technology transfer data for Canada and the United States. These data will serve as the primary source for the descriptive statistics and empirical analysis presented here.

2.1 Technology Transfer Trends in Canada (1995-2004)

The number of Canadian institutions that participate in the annual AUTM survey has increased significantly since the survey's inception (approximately 1991), perhaps reflecting an increase in both actual transfer activity as well as the survey's perceived importance (Figure 1). Although the number of participants has varied over time, a set of 10 Canadian universities, including most of the nation's largest research institutions, have participated regularly over the past 10 years (1995-2004, inclusive).[4,5] We turn next to provide a baseline description of technology transfer in Canada and offer some basic insights into how it has evolved over the past decade by studying the 10 institutions with 10 years of data and examining their: 1) resources applied to licensing, 2) invention disclosures and patents, 3) licenses and options executed, 4) licensing income, and 5) start-up activity.

2.1.1 Resources Allocated to Technology Transfer

The resources dedicated to technology transfer have increased over the past 10 years. Within the sample of 10 Canadian universities, the number of employees (full-time equivalents, or FTEs)

[4] The universities in this set include: Queen's University, Simon Fraser University, University de Montreal, University of Alberta, University of British Columbia, University of Manitoba, University of Toronto, University of Waterloo, University of Western Ontario, and University of Calgary. Perhaps the most notable omission from this set is McGill University, which for some reason did not participate in the 1996 survey.

[5] Although 17 Canadian universities participated in 1995, only 10 of those continued to participate consistently throughout the period under investigation.

more than tripled in ten years since 1995 from 50 to 160 (Figure 2).[6,7] Although there seems to have been a temporary decrease in staffing around the year 1999, perhaps related to the market correction that occurred at that time (March 2000) which was particularly focused on technology stocks, the overall trend has been almost consistently towards expanding resources allocated to technology transfer activities at these Canadian institutions.

It is important to note that this threefold increase is a significant underestimate of the real increase in expansion of transfer activities across the nation since by construction the data do not include universities that started technology transfer programs during the period in question. The analysis is presented this way since the data do not allow us to distinguish between universities without data in early years due to the absence of a technology transfer program versus those without data because they simply did not participate in the survey; thus, we condition on universities that participated throughout the 10-year period, offering a conservative view of the rate of growth with respect to university technology transfer activity at the national level.

In addition to the increase in staffing allocated to technology transfer, it is important to note that the financial resources allocated towards actual research also more than doubled over the period

[6] A "licensing FTE" is defined as a person employed in the technology transfer office whose duties are specifically involved with the licensing and patenting processes as either full or fractional FTE allocations. Licensing examples include licensee solicitation, technology valuation, marketing of technology, license agreement drafting and negotiation, and start-up activity efforts. "Other FTEs" are persons employed in the technology transfer office as either full or fractional FTE allocations whose duties and responsibilities are to provide professional, administrative, or staff support of technology transfer activities that are not otherwise included in "licensing FTE." Such duties may include management, compliance reporting, license maintenance, negotiation of research agreements, contract management, accounting, MTA activity, and general office activity. General secretarial/administrative assistance also may be included in this category.

[7] Only nine years of data are presented in this figure since the AUTM survey did not collect FTE data in 1996.

1996-2004 from CAD $1.0 billion to CAD $2.3 billion (Figure 3).[8] The data indicate that total sponsored research expenditures increased every year, on an aggregate basis across the sample of 10 Canadian universities, during this period.[9] Therefore, if we think of technology transfer in terms of a production function, two of the most salient input factors – research expenditures and technology transfer administrative infrastructure (measured in terms of dedicated FTEs) – both increased consistently over the study period.

2.1.2 Invention Disclosures, Patent Applications, and Issued Patents

Overall, the number of invention disclosures and patent applications, our first measure of technology transfer "output," also increased over the 10-year period starting in 1995 (Figure 4).[10,11] However, neither of these measures increased at the same rate as did the staffing resources allocated to technology transfer at the same set of institutions. Instead, the number of disclosures increased by approximately 68% and the number of patent applications increased by approximately 169% compared to the 220% increase in FTEs assigned to technology transfer activities.[12]

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[8] Only nine years of total sponsored research expenditures is shown in Figure 3 because Queen's University did not report this amount in 1995, thus distorting that year's aggregate expenditure.

[9] Total research expenditures include expenditures (not new awards) made by the institution in that fiscal year in support of the institution's research activities that are funded by all sources including the federal government, local government, industry, foundations, voluntary health organizations, and other non-profit organizations. Indirect costs are included.

[10] Only new patent applications are included in this measure. The count does not include continuations, divisionals, or reissues.

[11] It is important to note that the University of Waterloo did not report invention disclosures in 1995 and 1996 and the University of Manitoba did not report this value in 2001. In addition, the University of Waterloo did not report the number of patent applications in 1995. Extrapolating from adjacent years, one would not expect these missing values to greatly change the shape of the plotted lines.

[12] These 10 universities filed 738 disclosures in 2004 compared to 438 in 1995 (738/438 = 1.68); they filed 312 patent applications in 2004 compared to 116 in 1995.

Perhaps most interesting, the number of patents actually issued hardly increased at all. However, it is important to note that patents issued in a particular year actually relate to patenting activity from prior years since the average lag with respect to the issuing of a US patent is approximately three years. Also, the number of patents issued does increase during the middle part of the period under investigation, but the overall trend is not consistently upwards as it is in the metrics examined above.

2.1.3 Licenses and Options Executed

Next, we turn to a count of the number of license and option agreements executed.[13] A license agreement formalizes the transfer of technology between two parties, where the owner of the technology (the licensor, in this case, the inventing university), permits the other party (the licensee) to share the rights to use the technology. An option agreement grants the potential licensee a time period during which it may evaluate the technology and negotiate the terms of a license agreement.[14]

The number of licensing agreements and options executed remained reasonably stable throughout the 10-year period beginning in 1995 (Figure 5). With the exception of three years (1995, 1999, 2004), the set of 10 institutions generated approximately 200 new license and option agreements per year over the study duration. So, despite the almost consistent increase in the level of staffing at technology transfer offices over this time, the number of agreements executed remained nearly constant. This does not mean, however, that the value or quality of

[13] Each agreement, exclusive or nonexclusive, is counted separately. Licenses to software or biological material end-users of $1000 or more are counted per license. However, material transfer agreements are not counted as licenses/options in these data.

[14] In these data, an option agreement is not constituted by an option clause in a research agreement that grants rights to future inventions until an actual invention has occurred that is subject to that option.

these transactions remained constant. Thus, we now move from studying the frequency of agreements to the value of agreements by examining licensing income.

2.1.4 Licensing Income

Overall, our sample of 10 Canadian universities shows a reasonably consistent increase in running royalty income from licensing over time (Figure 6, 1996-2004).[15] 1999 and 2000 are exceptional years since licensing revenues decreased relative to prior years. This was likely due to the substitution of licensing royalties for equity and other forms of income during years that were famously characterized by US Federal Reserve Chairman Alan Greenspan as suffering from "irrational exuberance." Cashed-in equity and other forms of licensing income have been included in the graph along with the more traditional form of licensing income, running royalties, to illustrate their rise and subsequent fall which occurred in parallel with the peak in equity markets during that period.[16]

2.1.5 Start-up Activity

Despite the common perception of growing entrepreneurship on university campuses, the number of start-up companies initiated per year does not appear to have increased substantially over time (Figure 7, 1995-2004). Interestingly, while the number of start-ups initiated does increase during the early part of the "Internet boom" (1995-1997) as one might expect, the number begins to decline in 1998, at least two years before the equity market correction. This

[15] Only nine years of data are presented in this figure since licensing income was not recorded in the 1995 survey.
[16] Cashed-in equity includes the amount received from cashing in equity holdings, resulting in a cash transfer to the institution. The amount reported is reduced by the costs basis, if any, at which the equity was acquired. Excluded from this amount is any type of analysis or process whereby a value for the equity holdings is determined but a cash transaction does not take place through the sale of these holdings. Licensing income from sources other than running royalties includes: license issue fees, payments under options, annual minimums, termination payments, and patent expense reimbursement.

may be due to the narrow way in which AUTM defines a start-up. Start-ups include only those companies that were dependent upon licensing the institution's technology for initiation. If a technology was licensed to an existing "start-up" company, but not a company defined as above, or if a graduate student started a company without going through the technology transfer office, this is not counted as a start-up initiation. In other words, a software company (e.g., a "dot com") whose business is not predicated on technology *licensed* from the technology transfer office would not be included in this count measure. Still, the absence of measured growth in the number of university-based start-ups, even narrowly defined, is surprising.

Overall, the data presented in this section suggest upwards trends in resource allocations for technology transfer activities (i.e., FTEs and research expenditures) in Canada as well as upward trends in actual technology transfer activity in terms of certain measures (i.e., invention disclosures, patent applications, licensing income from running royalties) but constant or inconsistent trends (i.e., not consistently increasing) in other measures (i.e., patents issued, license and option agreements executed, cashed in equity, licensing income from sources other than running royalties, start-ups initiated).

While these data offer some sense of the direction in which technology transfer resources and activities are moving, they offer little insight into actual behaviour at an institutional level. The data also do not offer any benchmark against which Canadian institutions may be evaluated. We turn to this topic next, with a brief case study of the University of Toronto.

2.2 A Closer Look at a Single Institution – University of Toronto

In 2003, UofT, one of the largest research universities in the country, reported total sponsored research expenditures of approximately CAD $307 million. During the same year, the university reported 138 invention disclosures, 60 new US patent applications filed, three US patents issued, 40 licenses/options executed, approximately CAD $2.7 million generated in licensing income, approximately CAD $520,000 in legal fees expended, and seven start-up companies formed. This level of technology transfer activity may seem low, since it implies approximately $2.2 million of research expenditures per disclosure, $5 million per patent application, $100 million per issued patent, $7.5 million per license/option executed, $100 million per $1 million in licensing income, and $43 million per start-up. In addition, the legal costs imply that almost 20% of licensing income is spent on legal fees.

These numbers may seem surprisingly dismal and may lead the casual observer to wonder whether UofT is unusually inefficient at technology transfer. Table 1 offers a simple comparison of UofT's output with a US institution that is often associated with successful technology transfer – MIT. MIT exploited approximately 3.3 times as much in research expenditures during the same year and generated 3.3 times more invention disclosures. In other words, UofT is equally efficient as MIT in the production of invention disclosures (constant returns to scale). However, UofT is less efficient at producing patent applications (3.9 multiple), issued patents (50.7 multiple), and licensing income (8.0 multiple). At the same time, UofT is more efficient at producing executed licensing and option agreements (2.9 multiple) as well as start-up companies (2.1 multiple), and spends proportionately less on legal fees (18.0 multiple).[17]

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[17] These "multiples" are stylized since research expenditures reflect the amount that the university spent on research in that particular year (2003), whereas other measures, such as patent applications filed, reflect applications filed in

What are the implications for Canadian technology transfer as a whole? It is, of course, dangerous to draw general conclusions about the transfer environments of two countries based on a single year's data associated with only one institution from each country. The University of Toronto and MIT may be idiosyncratic for a variety of reasons. Therefore, in the following section, we offer an empirical examination of 160 institutions drawn from both countries to determine whether there are any systematic differences in the degree to which universities from these two nations commercialize research.

3. An Empirical Comparison of Technology Transfer

3.1 Data

The data used for this analysis is drawn from the 2003 AUTM survey. This survey contains information on 200 Canadian and American universities. However, only 160 of these institutions reported complete information. As such, the analysis presented here is based on these 160 observations, of which 22 (14%) are Canadian and 138 are American.

3.2 Descriptive Statistics

Compared to the average Canadian university, the average American university has 16% more experience in technology transfer, 74% more invention disclosures, 183% more patent applications, 207% more issued patents, and 247% more licensing income (Table 2).[18] One might be concerned that these differences are driven by the relatively skewed distribution of

that year but are likely based on research that was carried out in prior years. Comparing "multiples" assumes that these measures are changing at the same rate across institutions.

[18] Experience is measured in years since the program start date, which is defined as the first year in which at least 0.5 professional FTEs were devoted towards technology transfer activities.

American universities; although the average quality of universities may be similar across the two nations, America is known for its set of superstar institutions, such as the Ivy League universities and other world-renowned institutions like MIT, Caltech, Berkeley, and Stanford. However, Table 3 illustrates that, while the differences are less extreme, they even exist at the median levels, not just at the sample means.

At first glance, these statistics present a reasonably grim picture of technology transfer in Canada. However, it is important to note that the average American university in the sample also spends 132% more on research. (Surprisingly, though, they employ 17% less FTEs who are dedicated to technology transfer.[19]) Still, research volume may be confounding these simple comparisons. That is not unlikely since research expenditures are an obvious input into the production function for technology transfer. Therefore, in order to assess productivity in technology transfer, we next turn to a multivariate analysis where we control for the volume of research expenditures and technology transfer-specific infrastructure.

3.3 Regression Analysis

In this section, we conduct a preliminary analysis to explore the possibility of a "Canadian commercialization discount." In other words, are Canadian universities systematically less productive than their American counterparts in terms of technology transfer? We explore this question by estimating the following specification:

$$E\left[I_i \middle| C_i, X_i\right] = \exp(\alpha C_i + \beta' X_i + \varepsilon_i) \qquad (1)$$

[19] Including FTEs from both licensing and "other."

where the conditional expectation of the level of technology transfer (say, number of invention disclosures generated at institution i, I_i) is a function of whether institution i is Canadian, C_i, a vector of control variables, X_i, and a disturbance parameter, ε_i. In such a specification, we interpret a negative and statistically significant estimate of α as suggesting that Canadian universities are systematically less productive than American schools in technology transfer.

Since the first four relationships we estimate are based on dependent variables that take on only non-negative integer values (number of invention disclosures, number of patent applications, number of patents issued, number of start-ups formed), a Poisson-type model is appropriate. Examining the results from Poisson regressions reveals that these data are over-dispersed relative to the Poisson distribution: the χ^2 goodness of fit statistic is very large in all cases, rejecting the null of *mean=variance* at $P>0.0001$. Therefore, we use negative binomial regression, effectively adding a random effect to the model. In the fifth model, the dependent variable (licensing revenues), takes on a continuous value and so an ordinary least squares regression is used. We employ a semi-log model here since the distribution of licensing income is highly skewed.

Results are presented in Table 4. Similar to the comparison between UofT and MIT presented in the above section, Canadian universities seem to be equally productive in generating invention disclosures, after controlling for research expenditures and technology transfer FTEs. (Although the sign on the Canadian coefficient is negative, it is not statistically significant.) Also, similar to the example comparison, Canadian universities seem likely to produce more start-ups than their American counterparts, controlling for the salient input factors. However, also similar to

the UofT-MIT example, Canadian universities seem systematically less productive in generating patent applications, issued patents, and licensing income. Based on the parameters estimated in Model 5, Figure 8 illustrates the Canadian commercialization discount in terms of licensing income over a range of university sizes as indicated by research expenditures (holding other measures constant at their mean values).

It is important to keep in mind that these results are exploratory, having only had access to one year's worth of survey data. Since the relationships between research expenditures and the various technology transfer metrics are a function of time, time series data would allow for a more comprehensive analysis and also would facilitate including institution fixed effects. The results presented here, based on cross sectional data, assume steady states of these time-dependent relationships (i.e., in reality, the number of invention disclosures generated in year *t* is likely a function of research expenditures from several years prior to year *t*).

While the results presented here are not conclusive, they are certainly suggestive. To this end, they raise the question of why there might be a systematic discount in terms of commercializing university research in Canada. While scholars of the economics of innovation have not focused much attention on the comparison between Canada and the United States, there has been significant research seeking to explain variation in university technology transfer in general. These studies offer some insight into potential reasons for the apparent Canadian commercialization discount. We turn to a brief survey of these studies next.

4. Possible Determinants of Technology Transfer Productivity

While many potential determinants of technology transfer productivity have been suggested in the literature, four seem particularly likely as factors that could vary systematically across universities at the national level. These are: 1) national policies such as the Bayh-Dole Act in the US, 2) academic culture with respect to commercialization, 3) access to key resources such as venture capital, and 4) proximity to "anchor tenants" that have been shown to influence the regional innovation system with respect to commercializing early-stage technologies. We discuss each of these in turn next.

4.1 National Policy: The Bayh-Dole Act

In December of 1980, the US Congress enacted the Patent and Trademark Law Amendments Act, more commonly known as the Bayh-Dole Act.[20, 21] The Act facilitated an increased interest from industry in commercializing university inventions by creating: 1) certainty of title to inventions made under federal funding, 2) uniform patenting and licensing procedures across universities, and 3) the ability of universities to grant exclusive licenses. Overall, the primary objective of the Act was to encourage an increased level of university-to-industry technology transfer.[22]

Passage of the Act was motivated by the realization that university inventions were not moving effectively from the campus into industrial practise. In 1980, although the federal government

[20] The act is named after its two sponsors, Senators Birch Bayh of Indiana and Robert Dole of Kansas.

[21] The original statue was amended in 1984 and augmented in 1986.

[22] The Act was further bolstered by the founding of United States Court of Appeals for the Federal Circuit in 1982. The purpose of the Federal Circuit was to combine similar federal cases into a specialized appellate court. In particular, the Federal Circuit hears all appeals from any of the United States district courts where the original action includes a complaint arising under patent law.

held title to approximately 28,000 patents, less than 5% of these were licensed to industry for development of commercial products.[23] Many policy makers believed technology transfer was so limited under the pre-Bayh-Dole regime because of incentives and administrative costs. The government retained title and made inventions available through (cumbersome and bureaucratic) non-exclusive licenses to anyone who wanted to practise them. As a result, companies were reluctant to invest heavily into the development, manufacturing, and selling of new products since their competitors could also acquire licenses and directly compete.

Based on a detailed study of university patenting over the period 1965-1988, Henderson et al (1998) report findings suggesting that the Bayh-Dole Act did indeed have a significant impact on academic commercialization-related activities. The authors interpret their results as indicating that the Act successfully increased the incentives to patent and license whatever commercial inventions were produced; both the rate of patenting and the extent of licensing increased dramatically after 1980. In the popular press, *The Economist* referred to the Bayh-Dole Act as "possibly the most inspired piece of legislation to be enacted in America over the past half-century" and in reference to the temporary threat to America's technological supremacy in the late 1970s and early 1980s, particularly from Japan, the magazine argued "more than anything, this single policy measure helped to reverse America's precipitous slide into industrial irrelevance."[24]

Recently, many other nations have considered adopting some form of federal policy similar to the Bayh-Dole Act. In Canada, an Expert Panel on the Commercialization of University

[23] U.S. Government Accounting Office (GAO) Report to Congressional Committees, "Technology Transfer, Administration of the Bayh-Dole Act by Research Universities," May 7, 1998.
[24] From *The Economist* print edition, December 12th, 2002.

Research proposed an intellectual property (IP) policy framework that the authors stated would "inspire a transformational shift in culture within Canadian universities, as happened in the United States with the passage of the Bayh-Dole Act in 1980."[25] The IP policy framework proposed by the Expert Panel is very similar to the Bayh-Dole Act in spirit except that the proposed framework uses language throughout that mandates university IP management decisions be made in a manner that maximizes benefits to Canada.[26]

However, despite the general enthusiasm for Bayh-Dole as a federal policy to enhance technology transfer, a recent empirical examination of the effects of this Act is cautionary. In the most comprehensive review to date of the empirical evidence concerning the effects of Bayh-Dole, Mowery et al (2004) conclude that: 1) most of the increase in university patenting and licensing since the 1970s has been from research in the biomedical sciences (a field that really began to develop in the early 1980s, confounding the effects of Bayh-Dole), 2) the empirical support is mixed for the argument that patenting and licensing are necessary for the transfer and commercial development of university invention, 3) university patenting and licensing have negatively affected "disclosure norms" of academic research in specific fields, leading to higher levels of secrecy and less sharing among researchers of early results, and 4) the topic of increased assertion by institutional and individual inventors of property rights over inputs to scientific research is only just starting to receive scholarly attention.[27]

[25] "Public Investments in University Research: Reaping the Benefits," Report of the Expert Panel on the Commercialization of University Research, Advisory Council on Science and Technology, May 1999.
[26] Another technical difference that appears several times is that the Bayh-Dole Act requires "periodic" reporting to the federal government, where as the proposed policy requires "annual" reporting to the government.
[27] p. 95

Indeed, the authors go as far as speculating that "the Act's most important effect arguably was its provision of a congressional endorsement of patenting and licensing (including exclusive licensing) as appropriate activities for universities and public laboratories." In other words, they argue that it was the change in culture signalled by the change in law, rather than the change in law itself, that had the greatest effect on the attitudinal shift towards pro-commercialization of university science.

What does this mean for Canada? It is not obvious that Canada's existing regime is particularly different than what currently exists in the US under Bayh-Dole in terms of salient incentives for researchers and universities, even in the absence of a similar federal policy. To this end, IP ownership and royalty sharing information was collected from the 20 Canadian public institutions that received the largest amount of total sponsored research expenditures.[28] Information was collected from the institutions' websites and through phone interviews with the technology transfer offices of each institution.[29]

All 20 institutions studied have policies making disclosure mandatory for inventions that will (or in some cases could) be commercialized, although there is reasonable variation regarding the ownership policies concerning IP. Only 55% of the institutions have policies that grant IP ownership solely to the institution; 30% have policies that grant ownership to the inventor, and 15% have policies that grant joint ownership to the inventor and the institution. There is also

[28] The 20 largest were taken as listed in the AUTM Licensing Survey: FY 2003. These include: University of British Columbia, McGill University, Université de Montréal, University of Toronto, University of Alberta, Université Laval, University of Calgary, University of Western Ontario, University Health Network, Queen's University, Hospital for Sick Kids, University of Saskatchewan, McMaster University, University of Guelph, University of Ottawa, University of Waterloo, University of Manitoba, Université de Sherbrooke, Dalhousie University, Memorial University, Simon Fraser University.

[29] Data collection was carried out during October and November 2005.

variation in the way in which royalties are divided between inventors and their institution. Depending on which institution they are at, inventors can receive between 15% and 85% of the royalties generated from licensing their invention.[30] However, there does not appear to be confusion in the case of any of these universities regarding government or granting agencies taking ownership of research conducted at their campuses. Furthermore, all of these institutions seem to have the right to license inventions exclusively, should they see fit. Therefore, although a national policy such as Bayh-Dole may affect a change in principle, it is not clear how it would change any Canadian technology transfer activities in practice.

Moreover, it is important to keep in mind that upon surveying the existing body of empirical evidence and providing some new analyses of their own, Mowery et al (2004) conclude that "much of the current discussion of the economic role of US research universities and the contributions of US universities to the economic boom of the 1990s exaggerates the role of Bayh-Dole." While the importance of such a policy should not be completely dismissed, neither should full responsibility for Canada's commercialization discount be attributed to the lack of such a policy. Thus, additional factors influencing productivity should also be carefully considered. These are examined next.

[30] Unfortunately, there are not enough data to test hypotheses relating the effect of intellectual property ownership policies on commercialization performance. While there are reasonable variations in ownership and royalty distribution policies across universities as well as in performance as measured by licensing revenues, patents filed, and companies started, there are too many other factors that vary across institutions that could influence performance (omitted variable bias) to allow for compelling econometric analysis with these limited data. Unfortunately, it is not even feasible to collect time series data and use institution fixed effects since the variation in policies within institutions over time is very limited.

4.2 Culture: Role Models and Inventor Collaboration

A number of studies have examined whether differences in certain types of behaviour might explain differences in levels of technology transfer. To the extent that such cultural behaviour may vary systematically across countries, these issues may be relevant for explaining at least part of the Canadian commercialization discount. Bercovitz and Feldman (2004) examine inventor propensity to file invention disclosures within the medical schools of two prominent US institutions: Duke University and Johns Hopkins University. The authors find significant variation in propensity to disclose across individuals, departmental sub-units, and universities. Their findings suggest that at least part of the variation can be attributed to social/cultural factors.

For example, individuals who trained at institutions where participation in technology transfer was accepted and actively practiced were more likely to adopt these practices in their own careers. Also, faculty who completed their graduate education more recently, as commercialization became more accepted within the academy, were more likely to file disclosures. In addition, professors in departments where the chair was involved in commercialization were more likely to file disclosures. Finally, researchers whose peers engaged in commercialization activities were themselves more likely to file disclosures. It is possible that the culture at Canadian institutions differs systematically from that at American universities in some or all of the dimensions described above.

In a separate study, Agrawal (2006) found that firms that licensed inventions from MIT were more likely to successfully commercialize them if they involved the inventor in the development process. Perhaps surprisingly, firms varied significantly in the degree to which they involved the

inventor: one third of the sample did not engage the inventor at all. In this study, the sample is conditioned on inventions being disclosed, patented, and licensed. The dependent variables are measures of the likelihood and degree of commercial success. In other words, they indicate whether the license agreement generated any income to the university, and if so, how much. The variation examined is across licensed inventions from specific departments at MIT (mechanical engineering and electrical engineering/computer science).

While this study focuses on within-institution variation, it is not unreasonable to imagine that there might be a systematic difference across countries in the propensity to engage the inventor. This could be the case for at least two reasons. First, on the supply side, university researchers in Canada might be less inclined to collaborate on the commercial development of their inventions either due to cultural reasons (commercialization is considered less important than publishing new research) or policy reasons (their institutions may more strictly enforce the amount of time they can spend on commercially-oriented collaborations). Second, on the demand side, Canadian firms may be less likely to engage the inventor (assuming Canadian inventions are more likely to be licensed by Canadian firms). This could be due to cultural reasons (Canadian firms may be more inclined to want to do all development in-house) or institutional reasons (Canadian universities may be more cumbersome in terms of the bureaucracy imposed on licensee firms that wish to engage the inventor).

4.3 Resources: Access to Capital

It is often noted that there is relatively limited access to angel and venture capital in Canada as compared to the US. This could be relevant since a number of studies have indicated that access

to high-risk, early-stage capital influences the cost of forming technology start-ups (Tornatzky et al, 1995; Amit et al, 1998; Zucker et al, 1998; Wright et al, 2002). However, Shane (2004) notes that "to date, no large sample statistical studies have found support for the capital availability argument for geographical variation in [university] spin-off activity."[31]

In fact, in a study of the effect of local venture capital in the areas around US universities on the university spin-off rate from 101 universities over the period 1993 to 1998, DiGregorio and Shane (2003) found no evidence that the number of venture capital investments, the amount of venture capital invested, the number of venture capitalists, the amount of their capitalization, or the presence of university venture capital funds had a statistically significant effect on the level of university spin-off activity in a geographic area. Moreover, the empirical analysis presented in the previous section suggests that the Canadian commercialization discount does not apply to technology transferred through the formation of start-ups. Despite these statistical results, the interview notes presented in the final section of this paper suggest that access to sophisticated, early-stage risk capital was indeed very important to the formation and growth of at least one Canadian university spin-off company.

4.4 Local Demand: Anchor Tenants

To what extent might local "consumers" of university inventions influence the productivity of commercializing academic research? Agrawal and Cockburn (2003) examine this question in the context of three subfields of electrical engineering: medical imaging, neural networks, and signal processing. Unsurprisingly they find that the level of university research activity (as measured by journal publications) is correlated with commercialization activity (as measured by patents).

[31] p. 95

However, they also find that the degree to which regional economies convert local academic research into local commercial innovation varies substantially. They present evidence in support of the "anchor tenant" hypothesis as an explanation for at least part of this variation.

They define an anchor tenant as a large, local firm that is: 1) heavily engaged in R&D in general, and 2) has at least minor absorptive capacity in a particular technological area, such as medical imaging. The authors argue that by virtue of its participation in local markets for technology and specialized inputs, such a firm may confer significant externalities upon smaller innovative firms. These externalities may facilitate entry by smaller firms also seeking to utilize university research, lower their costs, and improve their prospects for future profitability and growth. More – and more efficient – activity by this fringe of smaller firms increases the impact of vertical knowledge spillovers in the local economy, above and beyond the direct consumption of local academic research by the anchor tenant.

To the extent that local anchor tenants do play an important role in the commercialization of university science, this may confer a significant Canadian commercialization discount. While there are certainly exceptions, such as Research in Motion's proximity to the University of Waterloo and Nortel's proximity to the University of Ottawa and Carleton University, on average Canadian universities are probably significantly less likely to have anchor tenants nearby, especially across a broad range of applicable technology fields, since there are disproportionately fewer companies of such scale in Canada, even after normalizing for the nation's smaller number of universities.

4.5 Is the Canadian Commercialization Discount a Bad Thing?

Perhaps a Canadian commercialization discount with respect to technology transfer has positive implications for overall welfare. Some economists have expressed concern that an increased focus on commercialization may induce university researchers to focus their energies on commercialization activities rather than basic research (Cohen et al, 1998; Henderson et al, 1998). While focusing on research with commercial application might be economically beneficial in the short run, it may not be in the long run. Arguably, it is more important for universities to provide basic research for long-term economic growth, since, due to appropriability problems, the market will underprovide basic research, but not necessarily applied research. Moreover, since basic research forms the basis of much subsequent applied research, it is important for long-term productivity.

However, recent research does not provide evidence that professors are substituting patenting for publishing. Agrawal and Henderson (2002) examine the publishing and patenting output of a subset of faculty at MIT and present evidence suggesting that these two activities appear to be complements rather than substitutes. Markiewicz and DiMinin (2005) examine the complement/substitute question more directly with data from a much broader sample of university researchers. Their results also suggest that publication production by university researchers does not decrease with patenting behavior but rather increases.

Several other recent studies also examine the patenting-publishing relationship at various European institutions, such as Van Looy et al (2005), which concerns researchers at K.U Leuven in Belgium, Buenstorf (2005), which concerns researchers at Max Planck Institute in Germany,

Carayol (2005), which concerns researchers at the University Louis Pasteur in France, and Breschi et al (2005), which concerns researchers at various institutions in Italy. All of these studies report similar findings: patenting does not seem to substitute for publishing. Rather, they seem to be complements in most cases.

Although the evidence appears to be mounting that patenting activity does not occur at the expense of publishing, enthusiasm for unconstrained patenting in the university context should be tempered by the recent findings of Murray and Stern (2005). In this study, which employs a particularly careful difference-in-differences identification strategy based on patent-paper pairs, the authors report findings that although publications linked to patents are associated with a higher overall citation rate, the citation rate after the patent actually issues declines substantially (by 9-17%). The authors note that the decline is particularly salient for articles authored by researchers with public-sector affiliations, such as university professors. They interpret their findings as evidence of an anti-commons effect that results from moving intellectual property from the public into the private domain.

5 Observations from the Demand Side[32]

In this section, we move from examining the supply side of technology transfer (universities and professors) to the demand side (firms). Although one must be cautious about drawing conclusions from a single example, the focal company discussed in this section offers unique insights. Not only is the firm a spin-off company from a Canadian university, but it is also based on a business model that is predicated on transferring technologies from universities. We begin

[32] The private company information and opinions presented in this section were collected by interview with Dr. Geordie Rose in February 2006.

by describing the company and its research collaboration network, we then describe features of the local setting at UBC and Vancouver that facilitated the formation and growth of such a company, and finally we summarize remarks from the firm's CEO regarding his observations with respect to determinants of Canadian technology transfer productivity.

5.1 About D-Wave Systems Inc.

D-Wave was spun out of UBC in 1999 and remains located in British Columbia. The company's mission since inception has been to commercialize superconductor-based quantum computer processors. This company is particularly interesting for the purposes of this study because, during the first five years of operation, the science on which D-Wave's commercial objective was based was reasonably state-of-the-art and "basic" in nature. As such, much of the research work in the field was conducted at universities. In fact, 77% of research, as measured by citation-weighted publications, was carried out in university research labs (Table 5).

In response to this distribution of research activity, D-Wave developed a unique organizational structure. While the company conducted some research in-house, it outsourced the majority of its research to universities around the world. D-Wave signed contracts with researchers from a variety of disciplines, including theoretical physics, experimental physics, and materials science. The scientists were all employed by public institutions, such as universities and government research labs. While D-Wave directly employed only six Ph.D. scientists at its headquarters in Vancouver, it counted 46 Ph.D.s in its research collaboration network. This represented a significant effort in terms of size: large competing firms such as IBM and HP (they claimed)

each employed fewer than 10 full-time equivalent scientists working on building a quantum computer.

By 2003, D-Wave had established a network that included research groups associated with 10 institutions: University of British Columbia in Canada, Chalmers University of Technology in Sweden, the Institute for Physical High Technology in Germany, the University of Sherbrooke in Canada, the University of Twente in the Netherlands, the University of Erlangen-Nurnberg in Germany, Comenius University in the Slovak Republic, the Institute for Low Temperature Physics and Engineering in Ukraine, University of Toronto in Canada, and the National Physical Laboratory in Great Britain.[33]

As incentive to join the network, D-Wave offered researchers partial funding for their research projects and access to other scientists, tools, and equipment within the network. In return, D-Wave optioned the right to take ownership of (or at least exclusive rights to) the IP developed by the research group and an opportunity to file for patent protection prior to any publication of results (which could result in a publication delay of up to 90 days). The terms of the relationship between D-Wave and the research labs in the collaboration network were outlined in a formal contract. This contract was the "glue" that held together disparate research activities scattered around the world and governed the flow of IP from nodes in the network to headquarters in Vancouver.

[33] As of this writing, D-Wave has changed its strategy and dropped much of the research collaboration network. The company is now focused on engineering rather than science, exclusively focusing on the development and commercialization of the processor.

D-Wave's collaboration network enabled the firm to access some of the leading scientists in key areas of superconductor-based quantum computing while securing the rights to key pieces of IP related to the technology of superconducting electronics. It also allowed the firm to access the expensive equipment these scientists used. In November 2001, two years after founding the company and having raised only $2.5 million in equity financing and $0.5 million in grant funding, the total value of capital equipment being used by researchers in the D-Wave network was $440 million.

By interim metrics, D-Wave's strategy of collaborating with universities and licensing or acquiring the resultant intellectual property rights seems to have been at least reasonably successful. In 2003, during a period characterized as a "chilly investment climate" for venture capital, the company raised $7 million in a round led by the prominent California-based VC firm Draper Fisher Jurvetson (DFJ). This was the first time DFJ invested in a Canadian company in its 18-year history; it was also the first time that any major VC worldwide invested in a company focused on building a quantum computer. By 2005, D-Wave had accumulated more patents issued on this topic than any other competing company; the firm had more than IBM, Hitachi, and Lucent combined (Table 6). Also, in late 2005, the World Technology Network short-listed Dr. Geordie Rose, founder and Chief Executive Officer of D-Wave, for a World Technology Award for his role in the design of the world's first commercial-scale quantum computer processor architecture.

Much of D-Wave's success to date can be attributed to its strategy of research collaboration with and licensing/acquiring intellectual property from universities. As noted above, D-Wave

engaged in these activities with universities in Canada, the US, and Europe. As such, we conclude this study by summarizing factors that enabled D-Wave to grow in British Columbia as well as a few salient observations of the differences noted by D-Wave in terms of commercializing university inventions from Canadian universities versus those from elsewhere.

5.2 Insights from D-Wave Systems Inc.

We explore insights from D-Wave along two dimensions. First, we examine features of the particular setting in which D-Wave was created that may have facilitated the firm accomplishing what it did. Second, we document the salient differences the firm encountered in terms of transferring technology from Canadian, American, and European institutions.

5.2.1 Factors that May have Facilitated D-Wave's Early Success at Technology Transfer

There were at least three notable features about the local environment that facilitated D-Wave's formation and growth: 1) a strong research culture at UBC, 2) a reasonable commercialization culture at UBC, and 3) the presence of sophisticated early-stage investors. The preliminary idea for building a superconductor-based quantum computer processor was developed by Alexandre Zagoskin and Geordie Rose. Dr. Zagoskin, who holds a Ph.D. in solid-state physics from the Institute for Low Temperature Physics and Engineering at the Ukrainian Academy of Sciences, had authored 53 peer-reviewed scientific articles as well as a widely used textbook on the quantum theory of many-body systems. He was a visiting fellow at UBC. Dr. Rose was a graduate student in the physics department at the same institution. Clearly, it was only because UBC had a strong and active research culture that a scientist like Dr. Zagoskin was visiting and interacting with graduate students.

While there may be very few billion-dollar companies that have spun out of UBC, there still appears to be a reasonable culture of commercialization on the campus. In particular, Dr. Rose took a course on commercializing technology where he developed many ideas for D-Wave and learned about licensing IP, writing a business plan, and raising venture capital. The UBC course, which was offered across departments and which allocated half the seats to MBA students and half to graduate students from science and engineering, also provided access to a network of industry people who guest lectured on topics related to commercialization. Finally, the university's commercialization culture was also reflected in the technology transfer deal that D-Wave ultimately negotiated with UBC. Although Dr. Rose characterizes the process at UBC as "overly bureaucratic," he notes that the technology transfer officers at that institution were particularly smart and professional to deal with.

Finally, Dr. Rose notes the importance of local access to sophisticated early-stage investors for the early success of his firm. The first investor in D-Wave was Mr. Haig Farris, who was the UBC instructor for the course on commercialization. Mr. Farris was also the co-founder of one of Canada's largest technology-oriented venture capital firms, Ventures West. Over the duration of the course, Mr. Farris got to know his student, Dr. Rose, and developed a level of trust in him that facilitated an investment, even though the project was considered unusually risky. In addition, Mr. Farris was able to attract other investors, such as Mr. Michael Brown who was the other co-founder of Ventures West as well as a coauthor of the above-cited report by the Expert Panel on the Commercialization of University Research. Not only did these individuals invest capital into the project, they also lent their expertise and credibility to support the venture's

success; ultimately these individuals were instrumental in helping D-Wave construct their research collaboration network. Finally, in a later round of financing, VC firm DFJ cited the involvement of sophisticated investors like Haig Farris as one of the main reasons they "felt comfortable getting involved with the project."

5.2.2 D-Wave Insights into the Canadian Commercialization Discount

In response to a question about whether he noticed any systematic differences about technology transfer from Canada, Dr. Rose replied, "No, but there are definitely differences in dealing with American universities relative to the rest of the world." Overall, D-Wave negotiated agreements to transfer IP from three Canadian universities (UBC, Sherbrooke, and Toronto), three American universities (Berkeley, Caltech, and Stanford), and five European institutions (Chalmers University of Technology in Sweden, the Institute for Physical High Technology in Germany, the University of Erlangen-Nurnberg in Germany, Comenius University in the Slovak Republic, and the Institute for Low Temperature Physics and Engineering in Ukraine).[34] Overall, Dr. Rose's experiences were that "the Canadian universities are very similar to the European institutions."

At the national level, Dr. Rose noted differences between American versus Canadian and European institutions along three dimensions: 1) the uncertainty and bureaucracy associated with negotiating a deal, 2) the experience level of technology transfer officers, and 3) intangibles such as trust and reputation.

[34] Relationships with the three American universities developed over the past two years, which is why these institutions were not listed above as part of the collaboration network as it existed in 2003.

Dr. Rose notes that, at least in the context of his negotiations, the American institutions were much more efficient to deal with:

> *In the US, they have very well-established and practically useful guidelines for dealing with companies that have been time tested. The American schools we have worked with have a long history of dealing with companies, and they've got it down. There is very little uncertainty in the process. Although it is not always favourable to the company coming in, you always know where you stand. Whereas in the other dealings we've had, with the European and Canadian entities, often the information you are given is almost so vague as to be not useful and the impression you're given is that every deal is done on an ad hoc basis, which makes it quite a bit more difficult going through the system. The American schools that we've dealt with know how to do it well and are very professional about it – it's almost like dealing with another company.*
>
> *A lot of my observations on this point can be boiled down to one statement: If everybody just copied Stanford's model with IP – that's as near to perfection as you're going to get from the point of view of a company that wants to either do work with a professor or do some kind of IP deal. At Stanford, our experience was that they put as few barriers as possible up to prevent the successful transfer of IP. The amount of bureaucracy we had to deal with was quite low. There was a professor we wanted to deal with and he found the right guy at the technology transfer office. We put together a deal. At the Licensing Office, they provided some edits to a form agreement. There were two people on their side, the professor and one tech transfer person, and us; whereas at some places we have worked with there are 11 signatures that are needed.*

Dr. Rose also notes that given the uncertainties associated with early-stage technologies, there can be quite a variance in what companies need with respect to the terms of a technology transfer agreement. As a result, experience on the part of the technology transfer officer can go a long

way towards reaching mutually acceptable contractual terms. Overall, he notes that American schools appear to be more experienced at negotiating such terms, particularly if they are non-standard:

> *If you go to a school and it has produced dozens and dozens of billion-dollar companies over the course if its life, the person who are you are dealing with in the tech transfer office has probably been involved with some of those deals. So they understand the process of turning something that is really new and quarter baked into something that is valuable. Experienced people will understand why someone is asking for something that may be non-traditional. But if you go to somewhere like Sherbrooke or UBC, there have been a limited number of billion-dollar successes, so the person you are dealing with has little experience in having a big win come out of the portfolio. So they are often not confident enough to negotiate outside of the box to facilitate a transaction. You get the sense sometimes when you deal with some groups that they really have no concept whatsoever about what it's like to try to commercialize a new technology.*
>
> *For example, when we did a deal at the University of Toronto, they would not even consider what we asked for, which was transfer of title to an invention. Why? Not for any business or academic reason; their approach was driven by dogma. They had a policy that they would only license technology, not transfer title. Ultimately we agreed to this, but it was not what we wanted. Other institutions that normally did not transfer ownership were willing to negotiate, given what we were trying to achieve. But that's not the way UofT did things and they were not willing to be flexible. So that really slowed down the process and eventually created a situation where we stopped paying attention to what was going on there because we weren't getting what we needed to move forward.*

Finally, Dr. Rose notes the importance of intangibles. Given the high levels of uncertainty associated with early-stage inventions, he argues that feelings of trust and comfort are important for successful technology transfer:

> *Intangibles are very important. Credibility, the feeling of comfort you get when dealing with a particular institution as opposed to another, is worth a lot. If you are going to make a big investment in something very risky and early-stage, you are more likely to feel good about technology from a big US school. You likely don't care that much whether you are paying $50k per year or $250k per year; what you really care about is whether or not the stuff works.*
>
> *For example, if you're working at Sun and you're trying to develop some kind of new processor, you are more likely to believe that a new idea coming out of Stanford is the right one than you are some place in the Slovak Republic. In fact, you are more likely to pay $1 million for the Stanford idea than you are to pay $10k for the Slovak idea, even if the Slovak idea is better. I believe that if you only want the technical developments, you can get them cheaper in Russia or China or India than in the US, but there is a trust and credibility issue. People are more familiar and comfortable dealing with the Stanfords of the world and are willing to pay more for the confidence they have in that and the ability of those people to produce something useful.*

In February 2007 D-Wave presented the first demonstration of a working prototype at the Computer History Museum in Silicon Valley.

5.2.3 A Caveat

It is important to offer a caveat to Dr. Rose's observations. Most notably, his firm has dealt with only three American universities and an equal number of Canadian schools. Importantly, the

American institutions that D-Wave has entered into agreements with are not typical. They are all outliers in a distribution that is highly skewed on many dimensions including prestige, quality, resources, experience in technology transfer, and commercialization success. In other words, Berkeley, Stanford, and Caltech do not represent "typical" American universities.

However, that may be precisely the point. Just as we would not throw out the outlier observations in a venture capitalist's portfolio when evaluating their performance, since performance in that industry is predicated on outliers, neither should we necessarily be too quick to dismiss the important role of America's superstar universities in the study of technology transfer. In addition to traditional benefits from size, such as economies of scale and scope, other benefits might be disproportionately conferred on these institutions such as heightened industry awareness of inventions, prestige to licensees of being associated with the institution, and more powerful alumni who may assist with all aspect of wealth creation and the development of breakthrough ideas. To the extent that this is true, Canadian policy makers may reflect on broader policy issues that could influence the productivity of technology transfer, including the merits of investing in the development of our own star institutions. However, we leave that debate for another day.

6. Conclusions

We reviewed Canadian technology transfer trends over the past 10 years and discovered that although inputs to the process of commercializing university science have increased consistently,

increases in outputs have been less consistent over this period. Inconsistent growth in patents issued and licensing revenues generated seem particularly concerning and warrant further investigation. Moreover, a pair-wise comparison between one of the largest research institutions in the country (University of Toronto) and an American counterpart (MIT) echo this finding. Furthermore, regression analyses based on a sample of 160 universities from Canada and the US also produce findings suggesting a Canadian productivity discount relative to the US.

Why might this be? The empirical literature concerning productivity with respect to the commercialization of university science provides a variety of potential explanations. Although the extant literature has examined variation in productivity along other dimensions, not Canada versus the U.S., certain determinants seem likely candidates. In particular, differences in commercialization culture and proximity to anchor tenants seem the most likely explanations for the commercialization discount, not federal policy differences such as the lack of an equivalent to the American Bayh-Dole Act.

Finally, detailed interview notes with the CEO of a Canadian firm that has engaged in university technology transfer in a variety of countries suggest that commercialization transactions are more efficient in the U.S. than in Canada or Europe. From this firm's perspective, this is for three reasons: 1) Canadian universities are more bureaucratic which makes deal-making slower and more tedious, 2) Canadian universities are less experienced which makes deal-making less likely to arrive at mutually agreeable terms since university negotiators are reluctant to deviate from template agreements, and 3) Canadian universities lack the superstar cachet of big US schools, such as MIT, Stanford, Berkeley, Harvard, Caltech, and Columbia that add value and comfort to

the transaction such that licensees are actually getting more than just technology from the deal. There does not appear to be a role for federal policy in addressing the first two of these issues, since they are institution-level problems. The third issue could be considered a federal level topic, but bears on a deep cultural debate regarding the centralization versus geographic distribution of federal research resources.

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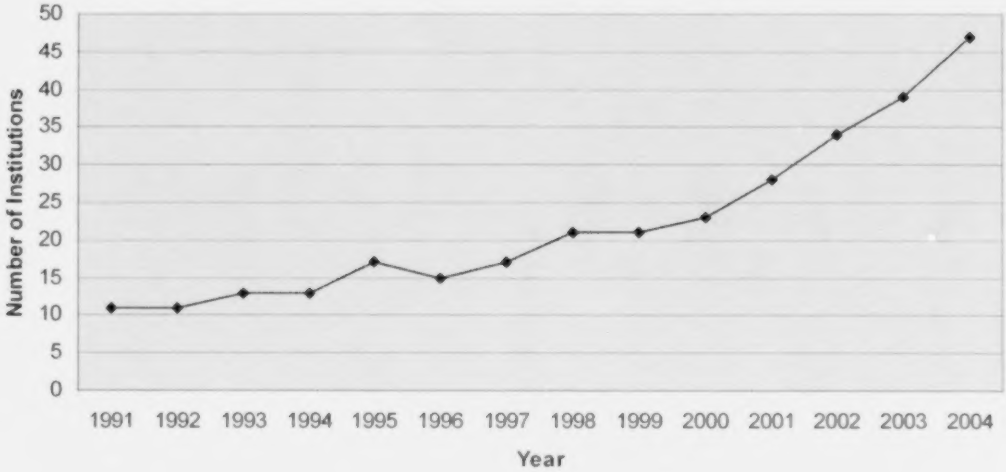
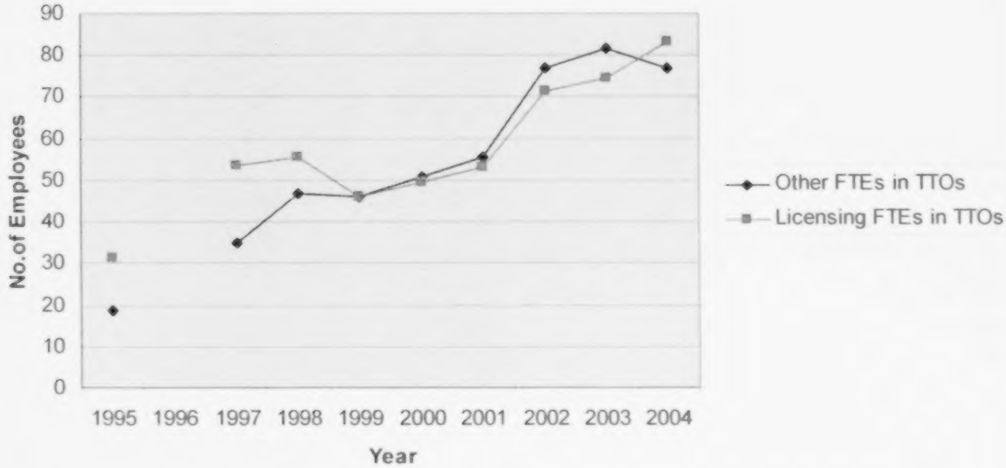
Figure 1
Number of Canadian Institutions Reporting Technology Transfer Data to AUTM (1991-2004)



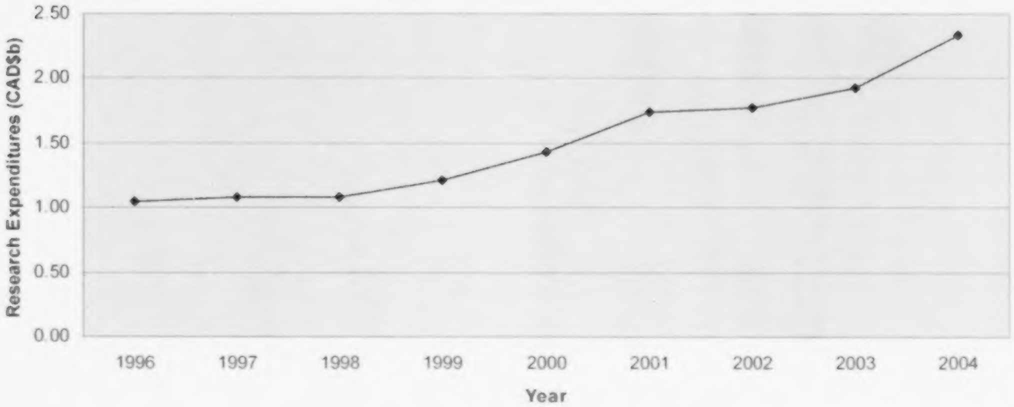
Source: AUTM Licensing Surveys: FY 1990-2004. The Association of University Technology Managers.

Figure 2
Number of Employees in Technology Transfer Offices
(10 Canadian Universities)



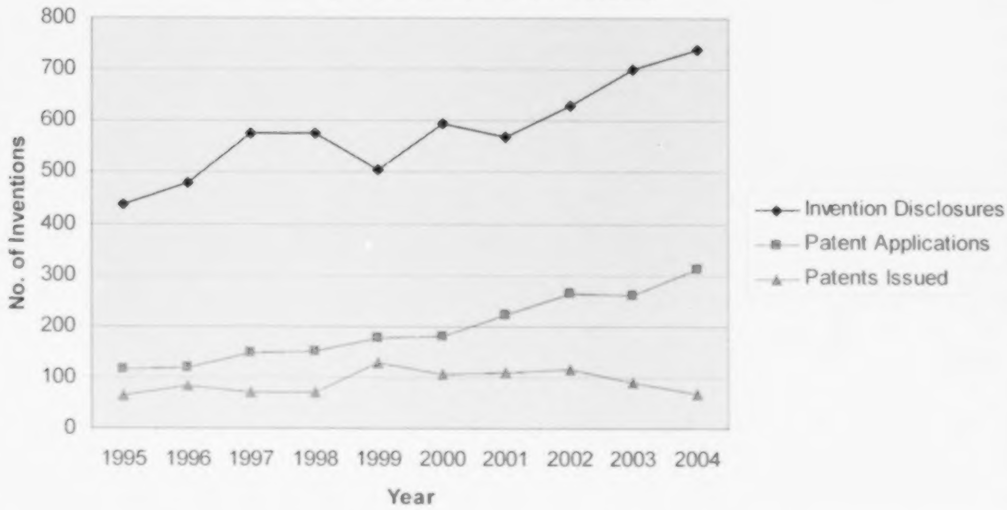
Source: AUTM Licensing Surveys: FY 1994-2004. The Association of University Technology Managers.

Figure 3
Total Sponsored Research Expenditures
(10 Canadian Universities)



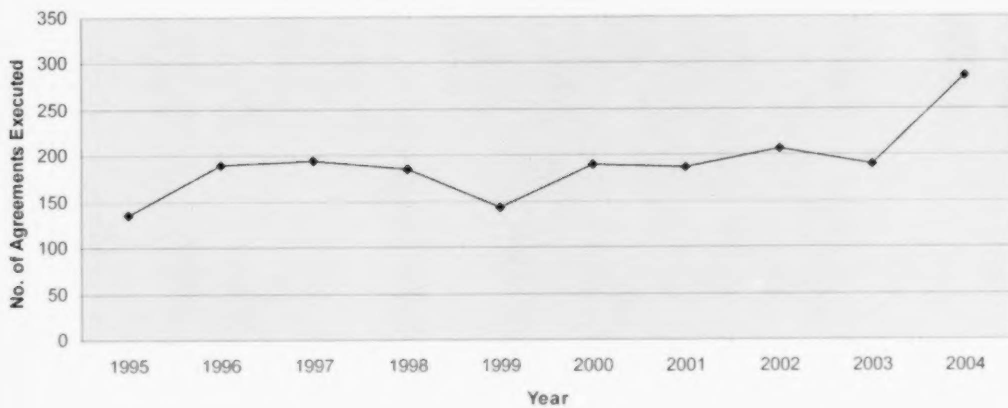
Source: AUTM Licensing Surveys: FY 1995-2004. The Association of University Technology Managers.

Figure 4
Invention Disclosures, Patent Applications, and Patents Issued (10 Canadian Universities)



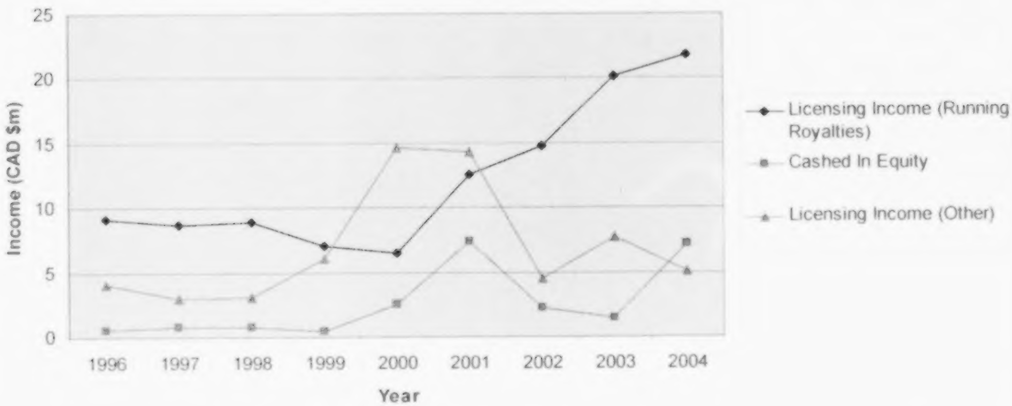
Source: AUTM Licensing Surveys: FY 1994-2004. The Association of University Technology Managers.

Figure 5
Licenses and Options Executed
(10 Canadian Universities)



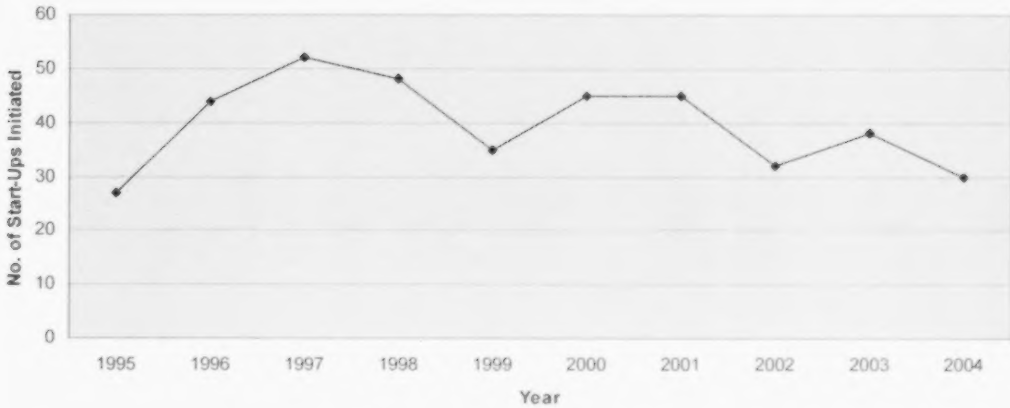
Source: AUTM Licensing Surveys: FY 1994-2004. The Association of University Technology Managers.

Figure 6
Income from Technology Transfer
(10 Canadian Universities)



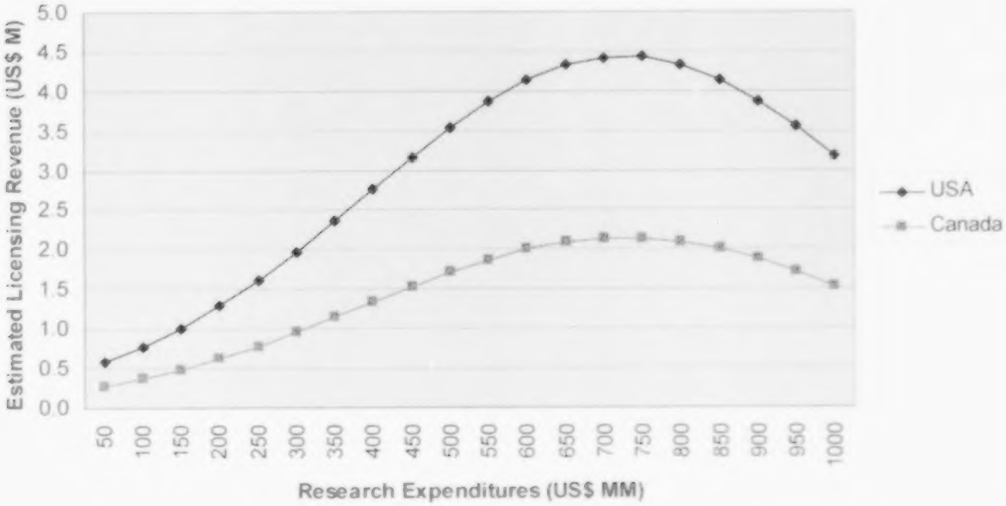
Source: AUTM Licensing Surveys: FY 1995-2004. The Association of University Technology Managers.

Figure 7
Start-ups Initiated
(10 Canadian Universities)



Source: AUTM Licensing Surveys: FY 1994-2004. The Association of University Technology Managers.

Figure 8
The Estimated Canadian Commercialization Discount



Source: AUTM Licensing Surveys: FY 2003. The Association of University Technology Managers.

Table 1			
Comparison between University of Toronto and MIT			
	University of Toronto	**MIT**	**MIT Multiple**
Total sponsored research (in millions)	CAD $300	US $1,000	3.3
Invention disclosures	138	452	3.3
New US patent applications filed	60	235	3.9
US patents issued	3	152	50.7
Licenses/options executed	40	114	2.9
Stock of licenses/options generating revenue	45	379	8.4
Licensing income (in millions)	CAD $3	US $24	8.0
Legal fees expenditures	$500,000	$9,000,000	18.0
Start-ups formed	7	15	2.1

Source: AUTM Licensing Surveys: FY 2003. The Association of University Technology Managers.

Table 2
Comparing Canada and the U.S.
Descriptive Statistics

	Canadian (N=22)				American (N=138)			
Variable	**Mean**	**Std. Dev.**	**Min**	**Max**	**Mean**	**Std. Dev.**	**Min**	**Max**
Research Expenditures (US$ MM)	101.5	76.9	4.8	269.0	235.8	300.7	4.3	2623.3
Licensing FTEs	5.4	4.3	0	16	4.5	6.9	0	73
Other FTEs	5.6	5.0	0	19	4.6	8.4	0	82
Experience	13.9	5.5	1	23	16.1	11.8	1	78
Invention Disclosures	52.3	48.9	2	155	91.2	120.6	1	1027
Patent Applications	17.5	19.1	1	78	49.5	67.2	0	490
Issued Patents	7.5	9.8	0	45	23.0	36.8	0	323
Start-ups	2.4	3.1	0	13	2.3	3.4	0	22
Licensing Income (US$ MM)	1.7	2.9	0.001	10.2	5.9	12.4	0.005	85.9

Source: AUTM Licensing Surveys: FY 2003. The Association of University Technology Managers.

Table 3
Canada versus U.S.
50% Percentile (Median) Values

	Canadian (N=22)	American (N=138)
Variable		
Research Expenditures (US$ MM)	81.3	145.4
Licensing FTEs	5	3
Other FTEs	5	2
Experience	15	14
Invention Disclosures	34.5	50.5
Patent Applications	10.5	27
Issued Patents	4.5	12
Start-ups	1	1
Licensing Income (US$ MM)	0.6	1.0

Source: AUTM Licensing Surveys: FY 2003. The Association of University Technology Managers.

Table 4
Estimation of a "Canadian Commercialization Discount"

	Negative binomial	Negative binomial	Negative binomial	Negative binomial	OLS
Dependent Variable	**Invention Disclosures**	**Patent Applications**	**Patents Issued**	**Start-Ups**	**Log Licensing Income**
Canadian	-0.168 (0.150)	-0.575 *** (0.179)	-0.475 ** (0.189)	0.841 *** (0.257)	-0.726 * (0.401)
Research Expenditures (in US$M)	0.004 *** (0.000)	0.002 *** (0.000)	0.003 *** (0.001)	0.004 *** (0.001)	0.006 *** (0.001)
Research Expenditures Squared (e-07)	-19.7 *** (2.39)	-17.6 *** (2.48)	-18.2 *** (2.62)	-15.0 *** (3.63)	-44.6 *** (6.06)
Licensing FTEs	0.096 *** (0.020)	0.012 (0.021)	0.008 (0.025)	0.035 (0.032)	0.204 *** (0.056)
Other FTEs	-0.002 (0.017)	0.026 (0.019)	0.032 * (0.019)	-0.052 ** (0.026)	0.004 (0.043)
Experience	0.003 (0.005)	-0.004 (0.006)	0.002 (0.006)	-0.023 ** (0.010)	0.009 (0.013)
Invention Disclosures		0.006 *** (0.001)	0.004 *** (0.001)	0.005 ** (0.002)	0.001 (0.004)
Patent Applications			0.001 (0.002)	-0.003 (0.003)	-0.002 (0.005)
Issued Patents				0.002 (0.006)	0.015 (0.011)
Start-ups					-0.048 (0.054)
Constant	3.016 *** (0.098)	2.484 *** (0.105)	1.500 *** (0.113)	-0.305 * (0.172)	11.632 *** (0.228)
Pseudo (Adjusted) R^2	0.1143	0.1315	0.1606	0.1429	0.5458

* significant at the 0.1 level, ** 0.5, *** 0.01; standard errors in parentheses; N=160

Source: AUTM Licensing Surveys: FY 2003. The Association of University Technology Managers.

Table 5
Distribution of Quantum Computing Research Activity by Type of Institution (1999-2000)

Rank	Institution Type	Weighted Publishing Activity	% of Total
1	University/College	10186	77%
2	Corporation	1647	12%
3	Public Institution	1447	11%
	Total	13279	100%

Source: Data Compiled from ISI Web of Science

Method: Publications counted include those that contain the term "qubit" or "entanglement" with false positives removed (e.g., articles regarding fish entanglement were removed). Ranking by institute type is based on weighted publishing activity, calculated as follows:

$$w_i = \sum_{j=1}^{N} (Citations_j + 1) * \left(\frac{n}{m}\right)$$

where w_i is the weighting of the i^{th} institution type, j is the publication, N is the total number of publications, $Citations_j$ is the number of times paper j has been cited by December 2003, n is the number of author addresses associated with publication j that are of institution type i, and m is the total number of addresses associated with publication j.

The category "public institution" includes publicly funded institutions that are not universities or colleges such as the National Research Council of Canada, the National Institute of Standards and Technology, and the Max Planck Institut fur Informatik.

Table 6

Distribution of US Patents Issued by Organization

Organization	Location	No. of Patents Issued
D-Wave Systems, Inc.	British Columbia	25
International Business Machines	New York	2
Hitachi, Ltd.	Japan	2
Kabushiki Kaisha Toshiba	Japan	1
Motoyoshi; Akio	Japan	1
Japan Science and Tech Agency	Japan	1
Silicon Graphics, Inc.	California	1
Jaeger; Gregg Scott	Massachusetts	1
Tucci; Robert	Massachusetts	1
Lucent Technologies Inc.	New Jersey	1
Comm. a l'Energie Atomique	France	1
Unisearch Limited	Australia	1
	TOTAL	38

Source: U.S. Patent and Trademark Website <http://www.uspto.gov>

Note: This list includes all US patents with the term "qubit(s)" in either the title or the abstract that were issued before December 22, 2005.